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Study of Gamow-Teller transitions from ^{132}Sn via the (p, n) reaction at 220 MeV/u in inverse kinematics

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Abstract. The charge-exchange (p, n) reaction at 220 MeV has been measured to extract the strength distribution of Gamow-Teller transitions from the doubly magic unstable nucleus ^{132}Sn. A recently developed experimental technique of measuring the (p, n) reaction in inverse kinematics has been applied to the study of unstable nuclei in the mass region around $A\sim100$ for the first time. We have combined the low-energy neutron detector WINDS and the SAMURAI spectrometer at the RIKEN radioactive isotope beam factory (RIBF). The particle identification plot for the reaction residues obtained by the spectrometer provides the clear separation of the CE reaction channel from other background events, enabling us to identify kinematic curves corresponding the (p, n) reaction. Further analysis to reconstruct the excitation energy spectrum is ongoing.

1 Introduction

The Gamow-Teller (GT) transition is the simplest among the spin-isospin responses of nuclei, characterized by the spin and isospin changes by one unit in nuclear wave function and no change in the spatial part. For medium heavy stable nuclei with neutron excess, it is well known that a major part of the sum-rule strength is pushed up to highly excited states so called GT giant resonance (GTGR) [1]. Therefore, measuring the GT strength distribution over a wide excitation energy region including the GTGR is essential for revealing the natures of the nuclear collectivity and the underlying residual interactions in the spin-isospin channel (see, e.g., Refs. [2, 3]).

The transition strength, B(GT), is connected to the half-life of an allowed β-decay. However, the excitation energy region that the decay can access is limited by the Q-value window. Instead the charge-exchange (CE) reactions at intermediate energies have long provided a powerful tool to populate such highly excited states and extract the strength through a well established relation between the measured cross section at the limit of null momentum transfer and B(GT) [4].

Recently, there was the development of a novel technique of measuring the CE (p, n) reaction on unstable nuclei provided as a radioactive isotope (RI) beam in inverse kinematics and the technique was first applied to the study of GT transitions from the unstable nucleus ^{56}Ni [5, 6]. The technique is based on the missing mass spectroscopy for reconstructing the momentum and energy transfers in the (p, n) reaction, i.e. the low energy recoil neutrons originating from the target are detected and their energies and

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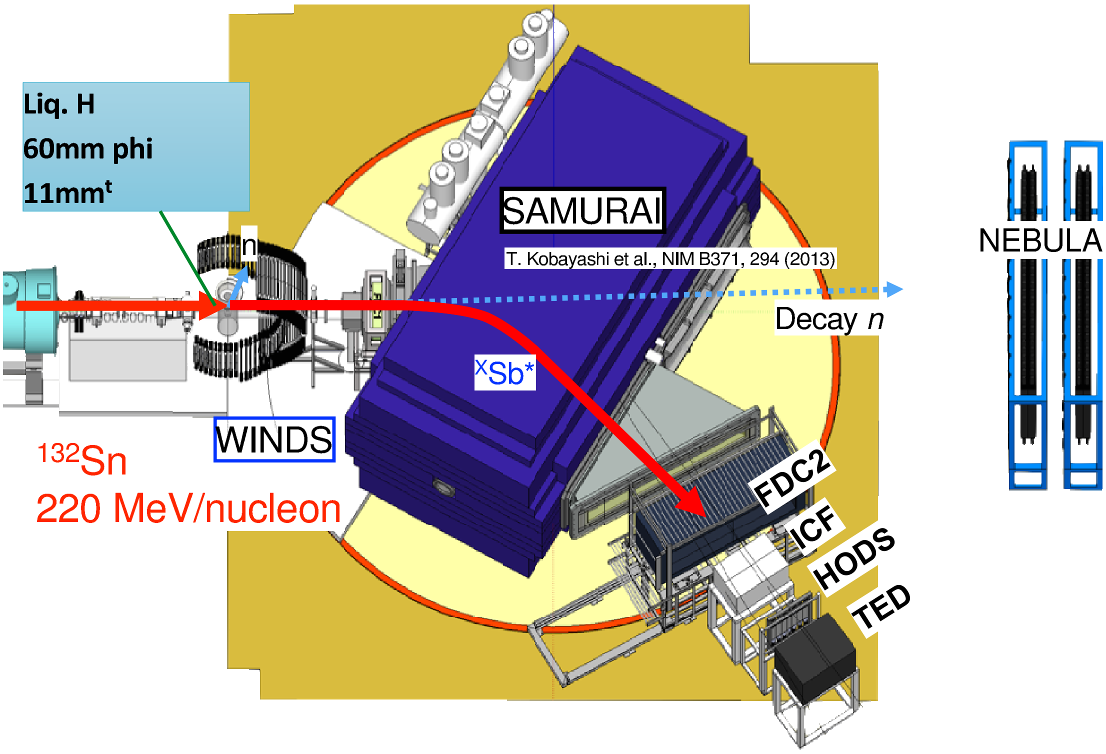

Figure 1. (Color online) A schematic view of the experimental setup around the SAMURAI spectrometer.

the laboratory scattering angles are used for obtaining the excitation energy and the scattering angle of the reaction. Thus, the reconstruction of the kinetic information does not depend on the final state of the reaction residue, although the reaction residue is detected in order to help the unambiguous assignment of the reaction channel. Owing to the simplicity of the missing mass spectroscopy, the application of the technique can be straightforwardly extended to a wider region of unstable nuclei with any mass or to higher excitation energies. It is contrast to the invariant mass spectroscopy, where all the decaying particles from the reaction residue must be identified and momentum analyzed and, therefore, the reconstruction of the kinematic information is more complex.

At RI beam factory (RIBF) of RIKEN Nishina Center, we are rapidly expanding the region of the spin-isospin study to a wide region of unstable nuclei using intense RI beams. In the present contribution, we show the experiment where the technique was applied to the region around the mass A=100 for the first time. The experiment was performed in order to study Gamow-Teller transition on the double magic nucleus ^{132}Sn in April 2014. The data analysis is ongoing and, herein, we show preliminary results indicating the identification of the CE reaction channel and the reconstruction of the kinetic information works well as planned.

2 Experiment and preliminary results

Figure 1 shows a schematic view of the experimental setup around the target. A secondary beam of ^{132}Sn at 220 MeV/nucleon was produced through abrasion-fission reaction with a 345 MeV/nucleon primary beam of ^{238}U and transported to a 11 mm thick liquid hydrogen target [7, 8]. The particle identification (PID) for the beam was performed on an event-by-event basis by measuring the energy loss (ΔE) in the ionization chamber at the F7 focal plane, the magnetic rigidity ($B\rho$) and the time of flight (TOF) of the beam particles in the BigRIPS spectrometer [9]. The resulting cocktail beam had a total intensity of 1.4×10^4 pps, containing ^{132}Sn with a purity of 45%. For tagging the CE reaction channels, the heavy residue was analyzed by the SAMURAI spectrometer [10]. The magnetic field of the spectrometer was set to 2.54 T. The PID was performed through the TOF-Bρ-ΔE method from the timing and energy loss information obtained in the plastic scintillator array HODOS and the particle trajectories reconstructed from the position information measured with the two drift chambers FDC1 and FDC2 placed at the entrance and exit of the spectrometer.

Figure 2 shows the decay scheme of the reaction residue produced through the (p, n) reaction. For covering the excitation energy region including the GTGR, the reaction residues $^{130-132}$Sb were identified. The PID spectrum is shown in Fig. 3 with respect to atomic number Z and mass-to-charge ratio A/Q for reaction residues produced from ^{132}Sn beam particles. The Z resolution is σ_Z=0.22 corresponding to 4.5σ separation for Z=50 and 51. The A/Q resolution is $\sigma_{A/Q}$=0.14% which corresponds to 5.4σ separation. The PID plot provides clear separation of the events due to the CE reaction channel from background events. Furthermore, owing to the large momentum ac-

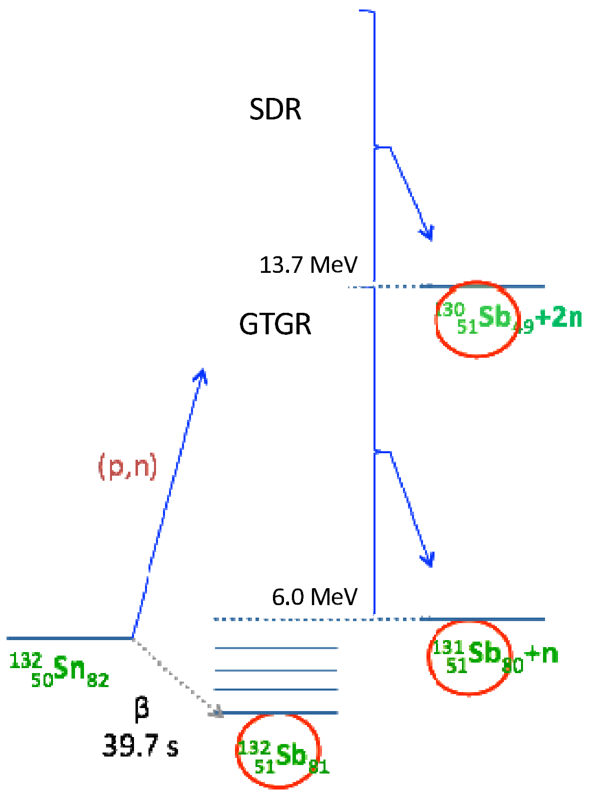

Figure 2. (Color online) Decay scheme of ^{132}Sb produced from the CE (p,n) reaction on ^{132}Sn. The heavy residues identified with SAMURAI, $^{130-132}$Sb, are enclosed with circles.

ceptance (50%) of SAMURAI spectrometer, all the reaction residues associated with the CE reaction channel can be identified in the same setting.

The target was surrounded by WINDS (Wide-angle Inverse-kinematics Neutron Detectors for SHARAQ) to detect recoil neutrons. WINDS consists of 61 plastic scintillators with dimensions of 600×100×30 mm^3. In this experiment 12 scintillators of the ELENS array [11] with dimensions of 1000×45×10 mm^3 were also installed. The left and right walls with respect to the beam line covered the angular region from 20 to 122 degrees with 5 degree steps. Top and bottom walls covered the angular region from 16 to 74 degrees with 3.5 degree steps. Each detector was placed such that the 30-mm wide (WINDS) or 10-mm wide (ELENS) plane faced the target and placed at a distance of 900 mm (1200 mm) from the target for the left and right (top and bottom) walls. Therefore, the ambiguity of flight-path-length (FPL) for the neutron (ΔFPL/FPL) was ±5.6% (4.2%) for left and right (top and bottom) walls.

The scattering angle (θ_{lab}) in the laboratory frame was mainly determined by the position of the scintillator bars. The angular resolution was estimated to be ±0.95 degree (±0.72 degree) for left and right (top and bottom) walls. The neutron energy (E_n) was determined by measuring the neutron TOF, for which the time reference was taken from the plastic counters SBT1,2. The absolute TOF scale was

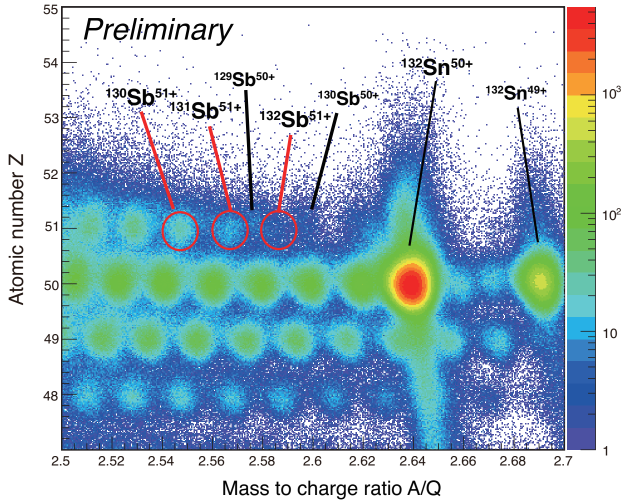

Figure 3. (Color online) A PID spectrum in the SAMURAI spectrometer for reacted events associated with the ^{132}Sn beam.

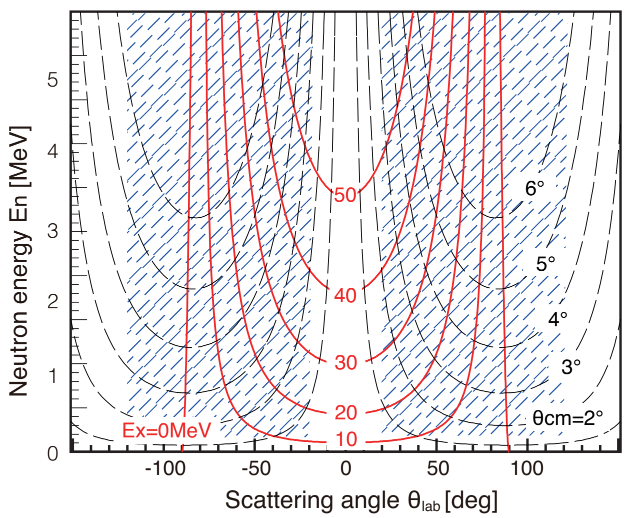

Figure 4. (Color online) Kinematic correlations for the (p,n) reaction on ^{132}Sn at 220 MeV/nucleon in inverse kinematics. The negative (positive) values of laboratory angle θ_{lab} correspond to placement of the bars on the left and top (right and bottom) side with respect to the beam line. The continuous curves indicate the correlation between neutron energy E_n and θ_{lab} for different values of the excitation energy in the residual nucleus from 0 MeV (g.s.) to 50 MeV with 10-MeV steps. The dashed curves indicate the correlation between E_n and θ_{lab} for scattering angles in the center-of-mass system ranging from 1 to 6 degrees with 1 degree steps.

obtained by measuring prompt γ-rays whose TOF can be reliably calculated from the light velocity and the flight path length. The resolution in neutron energy was estimated to be ±11%, mainly due to ΔFPL/FPL. Figure 4 shows the kinematic correlations for the ^{132}Sn(p,n) reaction at 220 MeV/nucleon. WINDS covered the laboratory angles from 20 to 90 degrees and the neutron kinetic energies from 0.2 to 20 MeV as shown by the shaded area. The threshold for the light output in the scintillator was set to

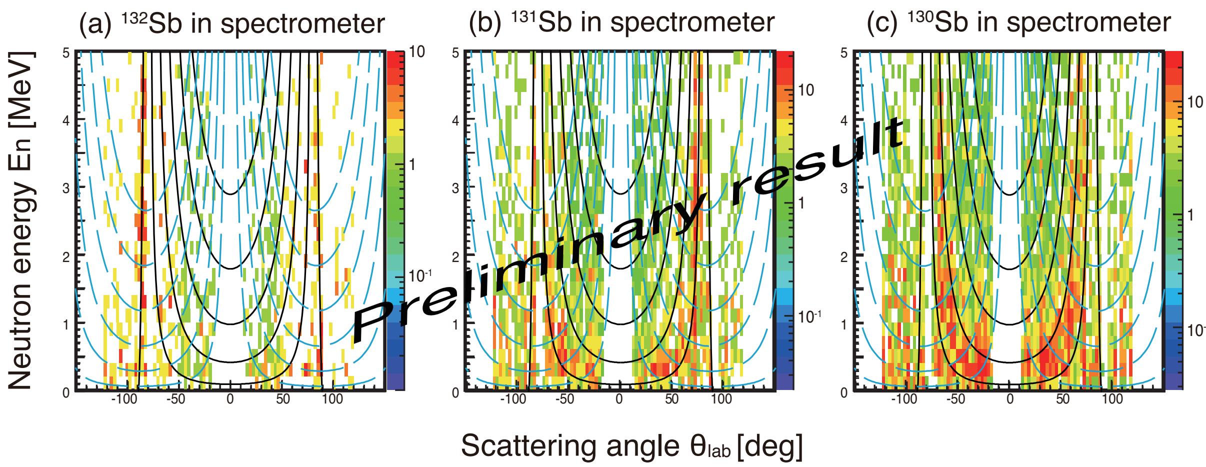

Figure 5. (Color online) Neutron spectra as a function of neutron energy (E_n) and scattering angle in laboratory frame (θ_{lab}) for the ^{132}Sn beam component and for events associated with the heavy fragments in the spectrometer: (a) ^{132}Sb, (b) ^{131}Sb, (c) ^{130}Sb.

be 60 keV electron equivalent, corresponding to 200 keV proton energy.

Figure 5 shows scatter plots of neutron energy (E_n) versus laboratory scattering angle (θ_{lab}) for neutrons detected in WINDS for events associated with the ^{132}Sn beam component. Scatter plots are shown separately for different residue species, i.e. $^{130-132}$Sb. Overplotted are kinetic curves shown in Fig. 4, along which one can clearly see kinematic correlation between E_n and θ_{lab} for the events tagged as the CE reaction. Depending on which final reaction residue the event is associated with, the loci moves from low, (a) to high excitation energies including the GTGR, (b) or (c). For reconstructing the excitation energy spectrum including the GTGR region, the data analysis is ongoing.

3 Summary

The charge-exchange (p,n) reaction has been measured on doubly magic unstable nucleus ^{132}Sn. We have combined the low-energy neutron detector WINDS with the SAMURAI spectrometer at RIKEN RIBF and applied the experimental technique of measuring the (p,n) reaction in inverse kinematics to unstable nuclei in the mass region around $A\sim100$ for the first time. The atomic number Z and mass-to-charge ratio A/Q of the beam residues was determined with resolutions of $\sigma_{A/Q}$=0.14% and σ_Z=0.22, respectively. By using the PID information, the events due to the (p,n) reaction populating excited states in a wide energy region including the GTGR were identified and the kinematic curves were clearly identified. It implies that the (p,n) study has been successfully extended to unstable nuclei in the mass region around A=100, although the analysis of reconstructing the excitation energy spectra is ongoing.

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